# A SYSTEM AND A METHOD FOR POLISHING OPTICAL CONNECTORS

## FIELD OF THE INVENTION

[0001] The present invention relates to the field of polishing connectors. More particularly the present invention relates to a method for polishing optical connectors and a system for implementing the method.

## BACKGROUND OF THE INVENTION

[0002] With the growth of optical communication networks there is a growing need for altering the network configuration, connecting to it new nodes and devices, disconnecting old devices and maintaining the network. These connections are easy and convenient to make with the help of an optical connector, which is a demountable device for attaching an optical fiber to another optical fiber, or to an active or passive device.

[0003] The losses of the optical signal power at each connection depend on the geometry of the connector end-face, matching surfaces geometry, surface quality and other parameters. In order to reduce optical signal power coupling losses the end-face of an optical connector typically comprising an optical fiber inserted into a ferrule is polished. The polished end-face surface may be flat, inclined or have a radius in accordance with the type of connection desired. The term "optical connector" as used herein in the description and claims denotes any polished end-face region of a fiber configured for optical connection to an adjacent element. Typically, the optical connector includes a fiber end inserted into a ferrule, although optical connectors without a ferrule (for example, certain MT type connectors) can also be polished using the systems and methods of the present invention.

[0004] Polishing of an optical connector on a piece-by-piece basis is not practical due to the nature of the process as well as the mix of the quantities and the structure of the connectors to be polished. This is the main reason why optical connectors are typically polished in batches. For polishing, a batch of optical connectors is mounted

in a so-called polishing fixture. US Patent No. 5,961,374 to Minami et al. discloses some such polishing fixtures. Figs. 1A – 1C illustrate some prior art polishing fixtures that may have round, polygonal, or any other form. In these polishing fixtures the connectors, marked by numeral 80, are mounted or attached to the periphery of a polishing fixture 82. Upon completion of the polishing operation, the connectors are removed from the polishing fixture and a new batch of connectors mounted. Mounting of the connectors along the periphery of the polishing fixture to some extent limits the number of connectors that may be simultaneously polished and the size of the polishing fixture.

[0005] US Patent Nos. 5,947,797, 6,183,343, and 6,190,239 all to Buzzetti disclose a polishing fixture (Fig. 1d) where the connectors or similarly configured industrial components to be polished are mounted across the fixture on a grid. This allows for simultaneous polishing of a relatively large number of optical connectors.

[0006] Polishing is usually conducted in the presence of a working liquid, which may be water, a specially formulated water-based solution, or any other fluid composition with suitable coolant and/or lubricant properties. For the purpose of brevity, the description of the invention below will refer to the working liquid by way of a preferred example as "water". Nevertheless, it should be appreciated that all other working liquids fall equally within the scope of the invention as claimed. Water plays an important role in the polishing process. Water cools the part being polished, removes particles, contamination and other debris that may destroy a polished connector end-face made up of the fiber and ferrule surface. The supply rate of water is controlled to maintain proper concentration of polishing slurry, and the water provides lubrication between polished parts and polishing substrate. Water (and sometimes other fluids) is usually delivered to the polishing member and to the actual polishing area, typically to the periphery of the polishing fixture by a fluid delivery system separate from the polishing fixture. The central and other parts of the polishing area do not get a sufficient amount of water. There is no method known to the inventors of the present invention of polishing a fiber and ferrule end-face on a rotating, linearly moving, or static polishing member that ensures proper water delivery to each and every polished connector mounted on the polishing fixture.

[0007] There is no polishing fixture known to the inventors of the present invention capable of delivering the proper amount of water to each connector or each part of a plurality of parts being simultaneously polished.

[0008] In the context of present invention, "polishing member" means a part having a surface with polishing slurry, or having a rigid or a resilient surface covered by polishing film or paper, on which actual polishing takes place. The terms "polishing film", "polishing paper", and "polishing member" in the context of the present invention are used interchangeably unless specified otherwise.

[0009] When separate optical patch cords are polished the excessive fiber length is mounted on a hanger, which in many instances is part of a polishing fixture. Recently the use of flexible optical circuits, which represent multiple fiber bundles and cables proper routed and laminated between two polymeric substrates, has increased. Polishing of the connectors, which are terminations of the optical fiber cables and bundles forming the flexible optical circuit, is a complicate task, since it requires support of the complete flexible optical circuit. The support of the flexible optical circuit should substantially eliminate relative movement between the polished connector and the flexible optical circuit. There is no commercially available solution for polishing of such flexible optical circuits.

[00010] Polishing film is an expensive material and its condition is important for proper polishing process. Rotating polishing members typically use only a small part of the polishing surface or film. Methods of optimizing use of polishing surface or film placed on such a rotating polishing support are disclosed in US patent No. 5,961,374 to Minami et al. Despite the various attempts described therein to optimize usage of the polishing materials, Minami et al. fails to address the fundamental drawback that polishing of the parts mounted on the polishing fixture takes place at differing speeds. Specifically, since the different parts are mounted at different distances or radiuses of the polishing disk, the rotating polishing action results in unequal polishing conditions and non-uniform wear of the polishing material.

[00011] US Patents Nos. 5,947,797; 6,183,343; 6,190,239; 6,302,763, and 6,428,391 all to Buzzetti teach polishing on a linearly moving polishing member. Movement of the stages holding the polishing material or member ensures a more

uniform polishing material usage and equal polishing speed of each of the polished parts. Buzzetti's patents do not, however, teach optimization of polishing material usage.

[00012] In both cases of a rotating or linearly moving polishing member, polishing film or paper exchange requires stopping the machine, removal of the previously used film, insertion of a new film, and restarting the machine for the next polishing cycle. This procedure results in considerable time wastage during the polishing process.

[00013] Polishing machines that use polishing film in the form of a web form are known in the art. These machines allow polishing film exchange by automatic polishing film advance, thereby saving time, as compared with machines using film sheets placed over rotating or linearly moving polishing film supports. In most cases, however, machines with automated advancing of polishing film tend to be inefficient in their use of the film. Loading and tensioning of polishing material on such machines is complicate and usually is performed by a number of rollers holding the polishing material and, in some cases, rotating or moving together with the polishing material.

[00014] The polished optical connector end-face surface may be flat or have a radius in accordance with the type of connector polishing desired. Flat fiber and ferrule end-faces are obtained by polishing on a flat rigid polishing surface or member. Polishing on a polishing member having resilient polishing surface results in a fiber and ferrule end-face having a curvature. There is no method known to the inventors of the present invention for polishing a fiber and ferrule end-face on a static, non-moving polishing member that results in a fiber and ferrule end-face having a curvature.

[00015] Polishing of optical connectors and some other photonic elements may be performed using a fixed set of polishing process parameters or in accordance with a predefined set of polishing process parameters sometimes called a recipe. Development of recipes requires collection of the results of a large number of polishing cycles and statistical processing of the results collected. This complicates instant correction of the polishing process that may be required from one to the next

polishing cycle. It would be desirable to have a system that has certain learning features enabling adaptation of polishing process parameters such as polishing speed, polishing time, and place on the polishing member selected in accordance with the results of the previous polishing cycle.

[00016] It would be also desirable to have an automated polishing systems incorporating in it the discussed features and providing a fully automated Photonic components set-up, polishing, cleaning and inspection cycle.

## SUMMARY OF THE INVENTION

[00017] The present invention is a polishing system for polishing optical connectors.

[00018] According to the teachings of the present invention there is provided, a polishing system for polishing optical connectors, the polishing system comprising: (a) at least one polishing station including a region of polishing film overlying a substrate block; (b) a polishing fixture having: (i) a plurality of connector mounting holes disposed across an area of the polishing fixture, each of the connector mounting holes receiving an optical connector, and (ii) a working liquid supply arrangement including a plurality of working liquid release channels for directing working liquid to regions adjacent to the connector mounting holes, at least one of the working liquid release channels being interspaced between a plurality of the connector mounting holes; and (c) a drive system for generating relative motion between the polishing fixture and the at least one polishing station so as to polish the optical connectors.

[00019] According to a further feature of the present invention, each of the connector mounting holes has a nearest neighbor spacing measured from the connector mounting hole to a nearest neighboring connector mounting hole, and wherein a spacing from each of a majority of the connector mounting holes to a nearest one of the working liquid supply channels is not more than twice an average of the nearest neighbor spacings.

[00020] According to a further feature of the present invention, a majority of the connector mounting holes are substantially equidistant from a nearest one of the working liquid supply channels.

[00021] According to a further feature of the present invention, the polishing fixture includes a mounting plate, both the connector mounting holes and the working liquid supply channels being formed as openings through the mounting plate.

[00022] According to a further feature of the present invention, the drive system is associated with the polishing fixture so as to move the polishing fixture along a two-dimensional polishing path relative to the at least one polishing station and wherein the at least one polishing station is configured to hold the region of polishing film static while the polishing fixture moves along the polishing path.

[00023] According to a further feature of the present invention, the drive system is further configured to raise the polishing fixture out of contact with the at least one polishing station on completion of a polishing operation.

[00024] According to a further feature of the present invention, the drive system is implemented as a set of three linear actuators.

[00025] According to a further feature of the present invention, there is also provided an optical cable support including at least one reel for receiving lengths of optical cables associated with the optical connectors being polished.

[00026] According to a further feature of the present invention, the cable support further includes a displacement mechanism configured to allow displacement of the reel in at least one direction.

[00027] According to a further feature of the present invention, a flexible optical circuit support rack associated with the polishing fixture for supporting a flexible optical circuit associated with the optical connectors being polished.

[00028] According to a further feature of the present invention, the flexible optical circuit support rack includes a clamping plate extending vertically above the polishing fixture, the clamping plate having a two dimensional array of bolt holes.

[00029] According to a further feature of the present invention, there is also provided a cleaning station including: (a) a wiping cloth supply roll; (b) a wiping cloth receiving roll; (c) a length of wiping cloth partially stored on the supply roll and stretched to the receiving roll to as to leave an exposed wiping cloth region; and (d) a winding actuator associated with the receiving roll and configured for actuating the receiving roll so as to bring a new portion of the length of wiping cloth into the exposed wiping cloth region.

[00030] According to a further feature of the present invention, the supply roll, the receiving roll and the length of wiping cloth are implemented as parts of a wiping cloth cassette.

[00031] According to a further feature of the present invention, there is also provided: (a) a polishing film feed mechanism for selectively exchanging the region of polishing film overlying the substrate block; and (b) a computerized controller for controlling the drive system and the feed mechanism, the controller being configured to: (i) actuate the drive system during a first polishing operation so as to move a batch of optical connectors in a polishing motion along a corresponding set of polishing profiles in contact with the static polishing film, (ii) actuate the drive system during at least one additional polishing operation so as to move a batch of optical connectors in a polishing motion along a corresponding set of polishing profiles in contact with the static polishing film, the polishing profiles of the additional polishing operation being interspaced with, and non-overlapping, the polishing profiles of the first polishing operation, and (iii) actuate the feed mechanism so as to advance the polishing film.

[00032] There is also provided, according to the teachings of the present invention, a polishing system for polishing optical connectors, the polishing system comprising: (a) at least one polishing station including a region of polishing film overlying a substrate block; (b) a polishing film feed mechanism for selectively exchanging the region of polishing film overlying the substrate block; (c) a polishing fixture having a plurality of connector mounting holes disposed across an area of the polishing fixture, each of the connector mounting holes receiving an optical connector; (d) a drive system for generating relative motion between the polishing fixture and the at

least one polishing station so as to polish the optical connectors; and (e) a computerized controller for controlling the drive system and the feed mechanism, the controller being configured to: (i) actuate the drive system during a first polishing operation so as to move a batch of optical connectors in a polishing motion along a corresponding set of polishing profiles in contact with the static polishing film, (ii) actuate the drive system during at least one additional polishing operation so as to move a batch of optical connectors in a polishing motion along a corresponding set of polishing profiles in contact with the static polishing film, the polishing profiles of the additional polishing operation being interspaced with, and non-overlapping, the polishing profiles of the first polishing operation, and (iii) actuate the feed mechanism so as to advance the polishing film.

[00033] There is also provided, according to the teachings of the present invention, a polishing system for polishing optical connectors, the polishing system comprising a cleaning station having: (a) wiping cloth cassette including: (i) a wiping cloth supply roll, (ii) a wiping cloth receiving roll, and (iii) a length of wiping cloth partially stored on the supply roll and stretched to the receiving roll to as to leave an exposed wiping cloth region; and (b) a winding actuator associated with the receiving roll and configured for actuating the receiving roll so as to bring a new portion of the length of wiping cloth into the exposed wiping cloth region.

[00034] There is also provided, according to the teachings of the present invention, a method for polishing optical connectors of a flexible optical circuit, the method comprising: (a) providing a polishing fixture including: (i) a plurality of connector mounting holes disposed across an area of the polishing fixture, each of the connector mounting holes receiving an optical connector, and (ii) a support rack for supporting a flexible optical circuit; (b) mounting a flexible optical circuit with a plurality of optical connectors mounted in the connector mounting holes and with at least part of a body of the flexible optical circuit attached to the support rack; and (c) generating relative motion between the polishing fixture and a polishing surface.

[00035] According to a further feature of the present invention, the relative motion is generated by a drive system associated with the polishing system, the polishing surface remaining static at least during a given polishing operation.

[00036] There is also provided, according to the teachings of the present invention, a method of polishing of the leading end face portion of a plurality of batches of optical connectors having a foremost end having a ferrule integrated with optical fiber, comprising steps of: (a) mounting first batch of optical connectors in a polishing fixture having a plurality of optical connectors mounting holes at a predetermined inclination angle and a plurality of working liquid delivery openings interspaced with the optical connectors mounting holes; (b) bringing the leading end faces of the mounted in the polishing fixture first batch optical connectors into forced contact with a static polishing member; (c) sliding the polishing fixture with the first batch of optical connectors simultaneously in two independent and orthogonal directions on the polishing member; (d) supplying through a plurality of openings and channels in the polishing fixture a working liquid to a plurality of optical connectors being polished and to the polishing member; (e) polishing the surface of the leading end face portion of the first batch of optical connectors by the sliding movement in a brushing pattern generated by independent changes of the sliding movement speed in each of the two orthogonal polishing fixture movement directions; and (f) controlling all of the polishing and auxiliary processes by a computer, the computer monitoring and memorizing all of the processes steps and parameters, wherein at least one of the polishing process parameters for polishing the surface of the leading end face portion of at least one of the following optical connector batches is changed by the computer, based on the results of previously polished optical connectors batch.

## BRIEF DESCRIPTION OF THE DRAWINGS

[00037] The invention is herein described, by way of non-limiting example only, with reference to the accompanying drawings, wherein:

[00038] Figs. 1A – 1D are schematic illustrations of prior art polishing fixtures;

[00039] Fig. 2 is a general block scheme of the optical connectors polishing system of the present invention;

[00040] Fig. 3 is a schematic top view illustration of the polishing station of the present invention;

[00041] Fig. 4 is a top view illustration of an exemplary embodiment of a polishing fixture of the present invention;

[00042] Figs. 5A and 5B are cross-sections of an exemplary embodiment of a polishing fixture of Fig. 4, which is part of the present invention;

[00043] Fig. 6 is a three dimensional representation of polishing fixture of Fig. 4 coupled with a bayonet type lock and a unit allowing its rigid or floating position on the polishing surface;

[00044] Figs. 7A and 7B are schematic illustrations of exemplary shapes of flexible printed circuit boards with optical fiber bundles and optical connectors;

[00045] Figs. 8A and 8B are respectively front and rear view of an exemplary polishing fixture of the present invention for polishing of flexible optical circuit boards with optical fiber bundles and optical connectors;

[00046] Figs. 9A and 9B are schematic illustrations of the polishing fixture of Fig. 8 the present invention for polishing of flexible printed circuit boards with mounted on it flexible printed circuit boards with optical fiber bundles and optical connectors;

[00047] Fig. 10 illustrates a polishing fixture for polishing of non-standard fiber length cable;

[00048] Fig. 11 is an illustration of an exemplary embodiment of a polishing sub-system of the present invention;

[00049] Fig. 12 is an illustration of an exemplary embodiment of a polishing unit of the present invention;

[00050] Fig. 13 is an illustration of an exemplary embodiment of a polishing film supply roll of the present invention;

[00051] Fig. 14 is an illustration of operating principles of an exemplary embodiment of a polishing film supply cassette unit of the present invention;

[00052] Fig. 15 is a schematic illustration of another exemplary embodiment of a polishing film supply and receiving cassette unit of the present invention;

[00053] Fig. 16 is a schematic three dimensional view of the of the polishing sub-system of the polishing station of the present invention equipped with polishing film supply and receiving cassette unit;

[00054] Fig. 17 is a schematic three dimensional view of the of the wiping cloth supply and receiving cassette unit of an exemplary embodiment of the present invention;

[00055] Fig. 18 is an illustration of a sliding movement pattern of the polishing fixture of an exemplary embodiment of the present invention and the resulting optical connector polishing trajectory;

[00056] Fig. 19 is an illustration of a method of economic use of polishing member by selection of different polishing areas, which is part of the present invention; and

[00057] Fig. 20 is a schematic illustration of polishing speed vectors of different parts of polishing fixture.

## DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[00058] The principles and execution of a method according to the present invention, and the operation and properties of a polishing system described thereby may be understood with reference to the drawings and the accompanying description of non-limiting, exemplary embodiments.

[00059] By way of general introduction, before addressing the drawings in detail, it should be appreciated that certain preferred implementations of the present invention provide a polishing system comprising a set-up station for proper position and mounting of a plurality of optical connectors to be polished and a polishing station. The polishing station optionally and preferably may include in addition to a polishing sub-system, a cleaning sub-system, a rinsing and drying sub-system, an inspection subsystem, and a control computer controlling the operation of all sub-systems and stations comprising the polishing system.

[00060] In accordance with one exemplary embodiment of the present invention the object of providing a method of polishing optical connectors or other photonic

elements in which each of the optical connectors or other photonic elements being polished gets equal and sufficient amount of water may be achieved by providing an optical connector polishing system for polishing optical connectors including a polishing fixture having a plurality of optical connectors mounting holes. The optical connectors mounting holes optionally and preferably are distributed across the area of the polishing fixture and not only along the perimeter of the polishing fixture. Mounting a plurality of optical connectors to be polished in the mounting holes of the polishing fixture, polishing the plurality of connectors mounted in the mounting holes of the polishing fixture and delivering water to each of the plurality of optical connectors being polished through the water delivery openings placed in the spaces between said plurality of optical connectors mounting holes.

[00061] In accordance with another exemplary embodiment of the present invention the object of providing a method of simultaneous polishing of a large number of optical connectors and other photonic elements in which the polishing speed of each optical connector and other photonic elements is equal may be achieved by mounting a plurality of optical connectors in a polishing fixture and polishing them on a flat static polishing member. The polishing fixture may optionally and preferably have a plurality of optical connectors mounting holes distributed across the surface of the polishing fixture and not only along the perimeter of the polishing fixture. Optionally but not necessary the mounting holes of the polishing fixture may be located on a grid.

[00062] The leading portion of an optical connector end-face may be polished to a flat surface by polishing it on a rigid flat static surface. In accordance with yet another exemplary embodiment of the present invention the leading portion of the optical connector end–face may be polished into a curved surface by said sliding movement in at least two orthogonal directions. The polishing member in this case is optionally and preferably a resilient, web-polishing member. The resilient web-polishing member is static in process of polishing.

[00063] A polishing fixture sliding mechanism capable of sliding said polishing fixture simultaneously in at least two orthogonal directions on the static polishing member provides all required for polishing fixture movements. The sliding

mechanism optionally and preferably slides the polishing fixture simultaneously in at least two orthogonal directions and the sliding speed in the first direction is independent and optionally and preferably different of the sliding speed in the second direction, and the sliding movement of the polishing fixture is a sum of the first and second independent movements. The polishing fixture sliding mechanism is further capable of applying a controlled force to said polishing fixture and measuring the advance or descent speed of the polishing fixture.

[00064] Economic polishing film usage in accordance with the present invention is achieved by positioning the polishing fixture holding a plurality of optical connectors to be polished on a first section of a static polishing member. Polishing the first plurality of optical connectors by operating said polishing fixture sliding mechanism capable of sliding said polishing fixture simultaneously in at least two orthogonal directions on the first section of static polishing member. Positioning the polishing fixture holding the next plurality of to be polished optical connectors on a second section of a static polishing member, where the second section is different from the first section and optionally and preferably does not overlap the first section. Polishing the second plurality of optical connectors by operating said polishing fixture sliding mechanism capable of sliding said polishing fixture simultaneously in at least two orthogonal directions on the second section of static polishing member.

[00065] In accordance with an additional exemplary embodiment of the present invention, a control computer controls the process of positioning the polishing fixture on the first section of the static polishing member and optionally and preferably records the coordinates of the first section or polishing area. The control computer calculates the coordinates of the second section or polishing area of the static polishing member and optionally and preferably positions on it the polishing fixture for the next polishing cycle. Control computer takes care that the second polishing area preferably does not overlap with the first polishing area. The polishing fixture sliding mechanism performs both the operational or polishing movement holding the polishing fixture with a plurality of optical connectors over the first section of the polishing member and the auxiliary movement of repositioning the polishing fixture next plurality of to be polished to the second section of a static polishing member.

[00066] The present invention provides a method of easy web polishing material exchange that does not require any special operator skills and maintains the same polishing film tension and adhesion to the underlying polishing member surface. In accordance with this method, the polishing film is provided in a polishing film supply cassette for supply and tensioning the polishing film.

[00067] According to one of the embodiments, the polishing film supply and tensioning cassette or roll is preferably a disposable cassette and comprises a hollow cylindrical core having first and second end with the polishing film wind on the hollow cylindrical core. The hollow cylindrical core with the film rotates on a shaft. Friction between the hollow cylindrical core and a pair of expandable cylindrical inserts holds the hollow cylindrical core on the shaft. The expandable cylindrical inserts change the force, and accordingly the torque, they apply to the hollow cylindrical core as a function of the pressure applied to them by outer tapered cylinders inserted at both ends of the hollow core and inner tapered cylinders. A flexible element, such as a spring inserted between the inner tapered cylinders generates the pressure. Both outer and inner tapered cylinders are movably coupled with a common shaft. One of external tapered cylinders is rigidly coupled with the shaft. Second external tapered cylinder can slide on the shaft, although it can be fixed in any sliding position and become rigidly coupled with the shaft. Inner tapered cylinders can slide on shaft, but preferably rotate with it. The tension of unwind film is regulated by the force required to overcome the pressure generated by the flexible element.

[00068] According to the present invention, the polishing film dispensed from the supply roll or cassette is tensioned and adhered to a polishing unit, comprising a rigid frame having a flat surface, and an elastic or rigid member, placed in a trough in the flat surface. The polishing film is supplied by a polishing film supply roll or cassette and is disposed on the elastic or rigid member surface of the polishing unit. The receiving cassette or roll is capable of incrementally unwinding and advancing the polishing film. Polishing film is advanced between the polishing cycles and remains static in the course of the polishing process. Water ensures polishing film adhesion to the resilient or rigid insert of the polishing member. The force required to advance the polishing film regulates polishing film tension and provides additional

polishing film adhesion force. The force is a function of the pressure developed by flexible element.

[00069] According to another exemplary embodiment, the polishing film cassette is preferably a disposable cassette containing in a common package both film supply roll and film receiving roll. The polishing film is tensioned in the cassette and the force required to advance the polishing film regulates polishing film tension. Exchange of the cassette causes simultaneous change of both film supply roll and film receiving roll.

[00070] According to yet another exemplary embodiment, the wiping cloth may be packaged in a cassette, which is preferably a disposable cassette containing in a common package both wiping cloth supply roll and wiping cloth receiving roll. The wiping cloth is tensioned in the cassette and the force required to advance the wiping cloth regulates wiping cloth tension. Exchange of the cassette causes simultaneous change of both wiping cloth supply roll and wiping cloth-receiving roll.

[00071] According to another exemplary embodiment of the present invention control computer optionally and preferably monitors and stores in the memory the polishing speed, polishing fixture descent speed, number of polishing cycles made on the same polishing area, amplitude, and speed of orbital or brushing movement, and results of polished parts inspection. Based on the previous polishing cycle parameters and results control computer calculates and provides at least one parameter for the next polishing cycle. Such polishing process parameter may be polishing speed, polishing time, force applied to the polishing fixture, place on the polishing member and others.

[00072] The methods as described above provide advantages over the prior art in that the polishing of the end faces of a plurality of optical connectors is done in identical polishing conditions. Adequate water supply to each polished connector prevents polished surface degradation by contamination due to polishing residuals, reduces potential of surface scratches, and maintains constant the polished parts temperature. Ample supply of water washes out polishing residuals and promotes faster conditioning of the polishing film or polishing member. Freedom from such

contaminations and polishing residuals increases the yield of optical connectors polished according to the present invention.

[00073] In addition, the present invention offers another advantage in providing all movements required for proper polishing by only two simultaneous sliding movements of the polishing fixture. The resulting movement of the polishing fixture over the static polishing member is a sum of these two independent sliding movements. By controlling the amplitude and phase of each of the independent movements, it is possible to generate any brushing or orbital movement trajectories of the polishing fixture. This makes the polishing sub-system architecture simple and the polishing machine less expensive. There is no need for complicate eccentric mechanical arrangements or pulleys supporting a limited amount of orbital movements and requiring additional sources of rotational or linear movement.

[00074] A further advantage of the present invention is that one polishing fixture sliding mechanism performs both the operational or polishing movement of sliding the fixture over a polishing area and the auxiliary movement of repositioning the polishing fixture over another section of a static polishing member.

[00075] An additional advantage of the invention is that the polishing member or film is static in the course of the polishing process. This simplifies the polishing film to the polishing unit surface or insert surface adhesion. A polishing film supply cassette that keeps the polishing film tension constant supplies the polishing film. A polishing film receiving cassette advances in case of need the polishing film in the intervals between two polishing cycles. The loading of the polishing film supply cassette is simple and does not require special operator skills. The polishing film tension is constant throughout the polishing process and contributes to the consistency of polishing results.

[00076] A further advantage provided by the method of the present invention is in the economic use of polishing material mounted on a static polishing member. The economic use of the polishing material is achieved by the lay out of optical connectors in the polishing fixture and by making each next polishing cycle on a new section or area of the polishing member not overlapping with the previously used section or area of the polishing member. The control computer keeps track of

polishing material sections or areas used for polishing in previous polishing cycles and selects for the next polishing cycle new sections or areas of the polishing member that do not overlap with the previously used polishing member sections or areas.

[00077] The present invention also supports consistency of the polishing process by introducing corrections based on the results of the previous polishing cycle in the next polishing cycle polishing parameters. Such polishing parameters may be polishing speed, polishing time and others, as may be required by the particular polishing process.

[00078] Turning now more specifically to the Figures, Fig. 2 is a general block scheme of the optical connectors polishing system of the present invention. The integrated, automated optical connectors polishing system 100 may include a polishing station 102 and a preparation station 104. A control computer 106 governs operation of both polishing station 102 and preparation station 104. Computer 106 may control all polishing system processes and in addition to this such processes as inspection, perform statistical process analysis, keep process and parts databases, and issue different reports. Additionally, control computer 106 may contain programs enabling the learning of processes. The learning capabilities support continuous polishing process improvement. They may identify process degradation parameters and indicate on reasons causing the process degradation. Alternatively, each of the stations may have its own dedicated computer. In this case, the distributed computers would communicate between them via a network.

[00079] Control computer 106 may control polishing station 102, preparation station 104, and optional robotic arm 110. Computer 106 may control all inspection processes, perform statistical process analysis, keep process and parts databases, and issue different reports. Additionally, control computer 106 may contain programs enabling process learning. The learning capabilities support continuous polishing process improvement. They may identify process degradation parameters, for example a worn-out abrasive, and may indicate reasons for said process degradation, which require some on-line compensation, for example, adding more time to a certain step.

[00080] An operator stand 108 with monitor and Graphic User Interface (GUI) allows interactive operator intervention into each stage of the process. Control computer 106 uses a monitor with Graphic User Interface to display process status, and provide the operator with other useful information and images of the work-pieces being processed. An optional robotic arm 110 for transfer of work pieces between preparation station and polishing station may also be included into the automated optical connectors polishing system 100.

[00081] The following description provides detailed information on some of the main components of an integrated, automated optical connectors polishing system of the present invention.

[00082] Fig. 3 is a schematic top view illustration of polishing station 102 of the present invention. Polishing station 102 may include a main frame 150 on which a flat and rigid plate 154 may be mounted. Optionally attached to the top surface of plate 154 may be some sub-systems included in polishing station 102. Fig. 3 shows a polishing sub-system 152 containing a number of polishing units 156. A cleaning unit 158 for cleaning polished optical connectors of polishing process contaminations may also be positioned on the top part of plate 154. For the simplicity of explanation, plate 154 is shown cut away in a number of places, as will be clear from the following description. A rinsing and drying unit 162 and wiping unit 164 may be located on the top part of plate 154. A cut-away region of plate 154 renders visible polished connectors inspection unit 166. Inspection unit 166 may optionally be positioned in a recess of the top plate 154 and may be attached to the bottom surface of plate 154.

[00083] Polishing fixture 200 with a plurality of optical connectors (not shown) is attached by means of bayonet type pins 250 (See Fig. 6) to a rigid mount 172. Rigid mount 172 optionally and preferably has freedom of movement in X, Y and Z directions. Digitally controlled linear actuators 174, 176, and 178 provide respectively movement in X, Y, and Z directions. Digital control facilitates independent movement in each of the X, Y, and Z movement directions. Linear actuators 174, 176, and 178 can move and position polishing fixture 200 to virtually any point located on the top part of plate 154 of polishing station 102. Linear actuators 174, 176, and 178 optionally and preferably provide both operational movements required for the

polishing of optical connectors, and auxiliary movements required for positioning polishing fixture 200. When moving polishing fixture 200 from one sub-system to other sub-system, linear actuators 174, 176 and 178 function as a built-in robotic system. The optional robotic arm 110 mentioned above, when present, is typically only required for displacements outside the range of the polishing system, or for additional functions such as automated set-up functions.

[00084] Some of the sub-systems of the polishing station and relevant to the invention will be explained now in detail. Fig. 4 is a top view illustration of an exemplary embodiment of a polishing fixture of the present invention. In accordance with this exemplary embodiment of the present invention the object of providing a method of polishing optical connectors in which all optical connectors being polished receive equal and sufficient amounts of water may for example be achieved by providing a polishing fixture 200. Polishing fixture 200 comprises a solid body 202 having a plurality of optical connectors mounting holes 204. Optical connectors mounting holes 204 optionally and preferably are distributed across the area of the polishing fixture, and not just along the perimeter of polishing fixture 200. As a preferred option, but not as a requirement, optical connectors mounting holes 204 of polishing fixture 200 are located on a grid. Mounting of optical connectors in mounting holes 204 is typically achieved by using clips or inserts as is known in the art. By way of one non-limiting example, a quick release insert, such as LC-12 Port Tablock, commercially available from Domaille Engineering LLC., Rochester, MN USA, (not shown) enables fast and easy mounting of a plurality of optical connectors (not shown) to be polished in mounting holes 204 of polishing fixture 200. Polishing fixture 200 has a plurality of water delivery openings 210 made in solid body 202 of polishing fixture 200. Water delivery openings 210 are located in the spaces between optical connectors mounting holes 204 and they terminate in conical flares 208 (Fig. 5B ) guiding water to every connector being polished . Holes 212, 214 and 216 assist in the mounting of polishing fixture 200 to unit 252 (shown in Fig. 6) enabling floating or rigid positioning and operation of polishing fixture 200. In the course of the polishing process, water is delivered to the polishing member and to each connector to be polished simultaneously through each active water delivery openings 210. Where not all connector mounting holes are in use, the water supply is preferably

only connected (or activated) to selected water delivery openings 210 adjacent to the mounting holes in use.

[00085] With regard to the spacing of water delivery channels or openings 210, it is a particularly preferred feature of one aspect of the present invention that the water delivery openings are interspaced between connector mounting holes 204. Preferably, a spacing from most or all of connector mounting holes 204 to a nearest one of the water supply channels 210 is not more than twice an average of the nearest neighbor spacings of the mounting holes themselves. Most preferably, most or all of the connector mounting holes 204 are substantially equidistant from the nearest water supply channel 210. Water delivery holes 210 may be randomly spaced/positioned on the polishing fixture or arbitrarily positioned according to any desired pattern, although the polishing results in some instances may be inferior for unevenly spaced holes compared to a substantially evenly spaced arrangement of working liquid delivery holes.

[00086] Parenthetically, it should be noted that, although described herein in the context of a preferred embodiment in which a polishing fixture moves across a static polishing station, the interspaced working fluid delivery channel feature of the present invention is also applicable to other configurations such as where a circular fixture is brought into contact with a rotating polishing disk.

[00087] Fig. 5A is a cross-section A-A of an exemplary embodiment of a polishing fixture of Fig. 4, which is part of the present invention. Cross-section shows that axis 220 of optical connectors mounting holes 204 has an inclination angle ALPHA. Use of an inclination angle for correcting mismatch between the apex of the curved polished optical connector end-face and the optical axis of the curved surface is known in the art, and is not part of the invention. Inclination angle ALPHA may be different for different types of optical connector. Consequently, for each type of connector, a polishing fixture having a different inclination angle may be required. Optionally quick release inserts (not shown) may be adjustable and change their angle to meet particular connector polishing requirements.

[00088] Fig. 6 is an isometric representation of polishing fixture 200 coupled with a bayonet type lock 250, and having a unit 252 which allows fixture 200 to be

positioned in rigid or floating relation to the polishing member surface. Unit 252 allowing rigid or floating positioning of polishing fixture 200 on the polishing member surface is described in detail in a co-pending co-assigned patent application no. WO 03/023537 and is not per se part of the present invention. Tubing 256 conducts water to water delivery openings 210. Receptacle (not shown) connects unit 252 to pressurized air supply. The applied air pressure controls the floating or rigid operational mode of unit 252. A carry handle 260 supports easy and convenient manual transportation of loaded by optical connectors polishing fixture 200 from preparation station 104 (Fig. 2) to polishing station 102. Optional robotic arm 108 uses bayonet lock 250 for transportation of polishing fixture 200 between polishing system stations. For the movements within the polishing station itself linear actuators 174, 176 and 178 optionally and preferably provide both operational movements required for the polishing of optical connectors, and auxiliary movements required for positioning polishing fixture 200.

[00089] Excess length of standard length fiber optics cables and patch cords is located during the preparation and polishing process on a hanger 268. Hanger 268 has protruding ends 270 that prevent slippage of fiber optics bundles in the course of the polishing process. This type of handling of the excess length of the fibers is suited for relatively short fibers such as standard 3 feet, 4 feet, and 6 feet length fiber optics cables and patch cords. In an ever growing proportion of cases, optical circuitry with much longer non-standard fiber length cable and flexible optical circuitry are used, ranging from 30 feet up to thousands of feet. These cases present more complicated handling requirements. An example of a support arrangement for mounting devices of these types will now be described with reference to Figs. 7A-9B.

[00090] Figs. 7A and 7B are schematic illustrations of exemplary shapes of flexible printed circuit boards with optical fiber bundles and optical connectors, referred to as flexible optical circuit boards 400. Typically, the layout of such boards takes arbitrary shapes matching the layout of the communication systems in which it will be placed. Numeral 402 marks optical fiber bundles incorporated in flexible optical circuit boards 400, and numeral 406 marks optical connectors attached to optical fiber bundles 402, although some of the bundles may be ended just by bare fibers and not by

connectors. Body 412 of flexible optical circuit board 400 has mounting holes 410 for mounting optical circuit board 400 in its packaging.

[00091] Polishing of such optical connectors incorporated in a flexible optical circuit board is complicated since the board should be supported during the process and preferably there should be minimal relative motion between polished connector 406 and board 400. Relative motion between polished connector 406 and flexible board 400 weakens the fiber to connector connection point and may result in a broken fiber or introduction of cracks into the fiber. Connectors coming out of flexible boards are not necessary equally spaced, fiber cable or bundles may have different lengths, and types of connectors connected to these fiber cables may be different.

[00092] Use of a polishing fixture having a plurality of connectors mounting holes spread across the surface of the fixture enables easier connectors positioning in the mounting holes than fixtures having the connectors mounting holes distributed along the perimeter of the fixture. Fig. 8A and Fig. 8B are respectively front and rear view of an exemplary polishing fixture of the present invention for polishing flexible printed circuit boards with optical fiber bundles and optical connectors. A polygonal prismatic mounting structure 420 is rigidly attached by means of four poles 424 to solid body 202 of polishing fixture 200. Polygonal prismatic mounting structure 420 has a plurality of mounting holes 428 to which the body of flexible optical circuit is preferably fastened for polishing purposes with the help of flexible optical circuit mounting holes 410.

[00093] Before the polishing process takes place, flexible optical circuitry 400 is mounted on polygonal prismatic mounting structure 420 and fastened to it. Fiber optics connectors 406 are inserted in mounting holes 204 of fixture 200.

[00094] Fig. 9 A and Fig. 9B are schematic illustrations of another exemplary polishing fixture of the present invention for polishing of flexible optical circuits with mounted on it flexible optical circuits with optical fiber bundles and optical connectors. Fig. 9A illustrates the case of mounting and polishing of two flexible optical circuits 400 and Fig. 9B shows the case of mounting and polishing of four flexible optical circuit 400. Other numerals mark like parts described in the previous

figures. Simultaneous polishing of both connectors that are part of flexible optical circuitry and fiber optic patch cords is possible.

[00095] Fig. 10 illustrates a polishing fixture for polishing ends of non-standard length fiber cable. Non-standard length fiber cables are typically mounted on reels, such as reels 430. Each reel may contain cables with length of 2000 meters or more. For polishing purposes, each real 430 is mounted on a reel rack 432, cable to be polished is clamped by clamp 434, and cable connector is fixed in a regular way in polishing fixture 200. Reel rack 432 is attached to guides 174 and moves with it in at least one direction during the polishing, thereby minimizing the length of the loop of free optical cable. The motion of the reels may be free, by linkage to part of the linear actuator system, or under operation of an independently actuable drive system. Reels 430 containing different length optical cables may be polished simultaneously.

[00096] Fig. 11 is an illustration of an exemplary embodiment of a polishing sub-system of the present invention. Polishing sub-system 152 includes a rigid frame 280 on which optionally, and preferably, a number of independent polishing units 156 are located. An individual polishing-film supply roll 282 (or optionally a cassette as will be described below) supplies polishing-film 286 to each polishing unit 156. Polishing-film receiving roll 284 or cassette advances a predefined length as required during the intervals between polishing cycles. Polishing-film receiving roll 284 also collects used polishing-film 286. Each polishing-film receiving roll 284 has an independent drive 294 (only one is shown). Polishing-film 286 is tensioned and adhered to top surface 288 of each polishing unit 156. Each polishing roll 282 may contain different type of polishing-film 286, and each polishing-film may be loaded with a different film tension.

[00097] Top surface 288 of each polishing unit 156 has a set of rulers 290 forming a trough in which, in accordance with the polishing process desired, a resilient material, such as rubber insert 292 or a rigid material insert 296, such as for example a glass or aluminum insert or pad may optionally be placed. When the end-face of optical connector has to be polished to a spherical shape, a rubber insert 292 or an insert of other suitable resilient material such as polyurethane is placed in the trough.

In case where the end-face of optical connector has to be polished to flat shape a rigid insert 296 is placed in the trough.

[00098] A cross section of an exemplary embodiment of a polishing unit 156 of the present invention is shown in Fig. 12. Polishing unit 156 consists of a solid body 304 with top surface 288. Top surface 288 has a set of rulers 290 (Fig. 11) forming a trough in which, in accordance with the polishing process desired, a resilient material such as rubber insert or pad 292 or a rigid material insert 296 (not shown) is placed. Polishing film supply cassette 282 supplies polishing film 286. As polishing film is dispensed under tension by polishing film supply cassette 282 it passes over a bar 306. Bar 306 has a semi-round shape, and a hole 308 extends through the whole length of bar 306. The semi-round shape of bar 306 serves as a polishing-film guiding radius, which prevents the bottom surface of polishing-film 286 from damage when it is advanced by pulling it from cassette 282. In addition to this, water is supplied through hole 308 extending through the whole length of bar 306 to the lower surface of polishing film 286. Water exits bar 306 through a series of small holes 352 (Fig. 14) that on one side are in fluid communication with water supplying hole 308 and on the other side are in contact with the bottom surface of polishing film 286. Water wets the bottom surface of polishing film 286 as it is advanced and enhances its adhesion with rubber pad 292 or rigid insert 296 (not shown). When all polishing film 286 contained in polishing cassette 282 is used, cassette 282, which is optionally and preferably a disposable cassette is easy pulled out and replaced by a new cassette.

[00099] Polishing-film receiving cassette or roll 284 (Fig. 11) collects used and advanced polishing-film 286. Used polishing film is wound on shaft 314. A motor 294 through a gear 318, only part of which is shown, rotates shaft 314 and pulls polishing film 286 out of cassette 282. When polishing-film receiving cassette or roll 284 (Fig. 11) is full, it is ejected by ejection handle 322. Adjustable mounts 324 serve for mounting and leveling of polishing unit 156 on the rigid frame 280 of polishing sub-system 152.

[000100] Operation of an exemplary embodiment of polishing film dispensing or supply cassette 282 will be explained in detail now. In accordance with the present

invention, polishing-film supply cassette 282, illustrated in Fig. 13, is optionally and more preferably a disposable polishing film supply cassette. Polishing-film supply cassette 282 provides a method of easy web polishing material exchange that does not require any special operator skills, and maintains the same polishing film tension and adhesion to the underlying polishing member surface.

[000101] Polishing-film supply roll or cassette 282 comprises a hollow cylindrical core 330, having first 332 and second 334 end with polishing film 286 (shown here cut away) wound on hollow cylindrical core 330. Friction between hollow cylindrical core 330 and expandable cylindrical inserts 338 and 340 holds hollow cylindrical core 330 on a shaft 336. External tapered cylinders 344 and 346 inserted at both ends of the hollow core press expandable cylindrical inserts 338 and 340 against inner tapered cylinders 348 and 350. One of external tapered cylinders for example 346 is rigidly coupled with shaft 336. Second external tapered cylinder for example 344 can slide on shaft 336, although it can be fixed in any sliding position and become rigidly coupled with shaft 336. Inner tapered cylinders 348 and 350 can slide on shaft 336. A flexible element, such as a spring 354 applies counter pressure tensioning inner tapered cylinders against outer tapered cylinders.

[000102] Fig. 14 is an illustration of operating principles of an exemplary embodiment of a polishing film supply roll or cassette unit of the present invention. Polishing film 286 is supplied as a roll deployed around a hollow cylinder 330 (shown here cut-away to reveal the internal elements of the supply roll). Within hollow cylinder 330 are a pair of tapered cylinders 348 and 350 which are biased outwards by a spring 354 so as to tend to expand a corresponding pair of expandable cylindrical inserts 338 and 340, thereby generating friction braking force on the inside surface of hollow cylinder 330. A stopper pin 356 engages with a notch in solid body of polishing unit 304 and prevents rotation of shaft 336, and hence also of expandable cylindrical inserts 338 and 440. The tension of unwind polishing-film is thus regulated by the force necessary to overcome the braking torque created by expandable cylindrical inserts 338 and 440 bearing outwards on hollow cylinder 330.

[000103] Polishing-film supply roll or cassette 282 is optionally and preferably a disposable cassette. Cassette manufacturer regulates the preload generated by

flexible element 354. This ensures a constant and equal value for each cassette and accordingly constant and repeatable film tension values.

[000104] In another exemplary embodiment of the present invention shown in Fig. 15 and Fig. 16, polishing-film supply and collecting cassette is optionally and preferably a disposable cassette comprising mounted in a single body 362 polishing-film supply roll 282 and polishing film-receiving roll 314. The tension of polishing film 286 is set during the cassette assembly process and it is regulated by the force necessary to overcome the torque created by the force applied by flexible element 354 (Figs. 13 and 14) to inner tapered cylinders 348 and 350. Cassette body 362 snaps into its position on each polishing unit 156. Polishing film-receiving roll 314 engages through gear motor 294 that enables polishing film movement and exchange.

[000105] In yet another exemplary embodiment of the present invention shown in Fig. 17, a wiping cloth and collecting cassette is optionally and preferably a disposable cassette comprising mounted in a single body 368 wiping cloth 370 supply roll and wiping cloth receiving roll. The tension of wiping cloth 370 is set during the cassette assembly process and it is regulated similarly to the polishing film regulation tension. Cassette body 368 snaps into its position on a polishing unit 156 or a structure similar thereto. No water is supplied through the wiping process.

[000106] Polishing fixture-sliding mechanism includes X and Y-axis drives 174 and 176 (Fig. 3), respectively, and control computer 106 (Fig. 2). The sliding mechanism optionally, and preferably, slides the polishing fixture simultaneously in at least two orthogonal directions and the sliding speed in the first direction is independent and different of the sliding speed in the second direction, and the sliding movement of the polishing fixture is a sum of the first and second independent movements. Control computer 106 generates the type of movement desired and through digital control means controls the speed of the independent movement of each linear drives 174 and 176. Digital control means driving X and Y linear drives 174 and 176, with suitable signals, may achieve in addition to polishing movement an orbital or brushing movement of polishing fixture 200 (Fig. 4 and Fig. 6). For example, driving one of the linear drives with a signal of form Ksin(ω) and the other with a signal of

form Kcos(ω), where both signal have an equal frequency and amplitude, will result in circular orbital movement shown in Fig. 18 by line 380. Changing the amplitude of one of the drive signals will result in an elliptical orbital movement. Other orbital movement patterns, such as the figure eight, shown by line 382 and others may be achieved by changing the drive signals shape, frequency, and amplitude. The polishing fixture sliding mechanism is further capable of applying force to polishing fixture 200 schematically shown by bayonet type lock 250, and unit 252 allowing its rigid or floating position on polishing member (film) surface 286 and measuring polishing fixture descent speed. Numerals 282 and 286 indicate polishing film supply cassette and polishing film receiving cassette respectively.

[000107] Fig. 19 is an illustration of an economical method for use of a polishing member by selection of different polishing sections or areas on polishing member. Economic polishing-film usage in accordance with the present invention is achieved by: (a) positioning polishing fixture 200 holding a plurality of optical connectors to be polished on a first polishing section or area 384 defined by the boundaries of polishing fixture 200 on a static polishing film (member) 286; (b) operating said polishing fixture sliding mechanism capable of sliding said polishing fixture simultaneously in at least two orthogonal directions on the static polishing member 286 for polishing said first plurality of optical connectors; (c) positioning next polishing fixture 200' holding the next plurality of to be polished optical connectors on a second polishing section or area 386 defined by the boundaries of repositioned polishing fixture 200' on a static polishing film (member) 286, where the second polishing area 366 is different from the first polishing area 384 and does not overlap with first polishing area; and (d) operating said polishing fixture sliding mechanism capable of sliding said polishing fixture simultaneously in at least two orthogonal directions on the second polishing section or area of the static polishing member for polishing said second plurality of optical connectors.

[000108] In accordance with an additional exemplary embodiment of the present invention, control computer 106 (Fig. 2) optionally and preferably controls the process of positioning polishing fixture 200 on first polishing area 384 on static polishing member 286 and optionally and preferably records the parameters (coordinates) of first polishing area 384. Control computer 106 calculates

coordinates of second polishing area 386 on static polishing members 286 and optionally and preferably positions on it polishing fixture 200 for the next polishing cycle. Control computer 106 takes care that second polishing area 386 preferably does not overlap with first polishing area 384.

[000109] Digitally generated and controlled orbital movement combined with a static polishing member provides a number of options and benefits that existing conventional rotating disk polishing mechanical systems do not support. Change of orbital polishing pattern movement is one of them in addition to this variable speed within the same orbital movement pattern is possible. The flexibility of movement patterns combined with better speed control provides a higher polished surface quality.

[000110] Digital control of the speed of orbital movement pattern facilitates better polishing speed control. The parallel motion is also advantageous, equalizing the polishing speed of different optical connectors mounted on polishing fixture 200 and polished on a static polishing member. Fig. 20 is a schematic illustration of polishing speed vectors of different parts of polishing fixture 200. The use of a static polishing member together with the sliding movement mechanism under digital control ensures. that all of the connectors move along the same polishing path simultaneously and at the same speed. The capability of positioning polishing fixture 200 on practically any area of polishing member 286 enabled by X-Y stages movement and digital orbital control allows better polishing paper utilization and an overall increase in machine throughput.

[000111] While the exemplary embodiments of the present invention have been illustrated and described, it will be appreciated that various changes can be made therein without affecting the spirit and scope of the invention.